

# Photons and Dileptons

What have we learned at RHIC?

## Outline

- *Motivation*
- *p+p and Au+Au dielectrons*
- *Direct photons*

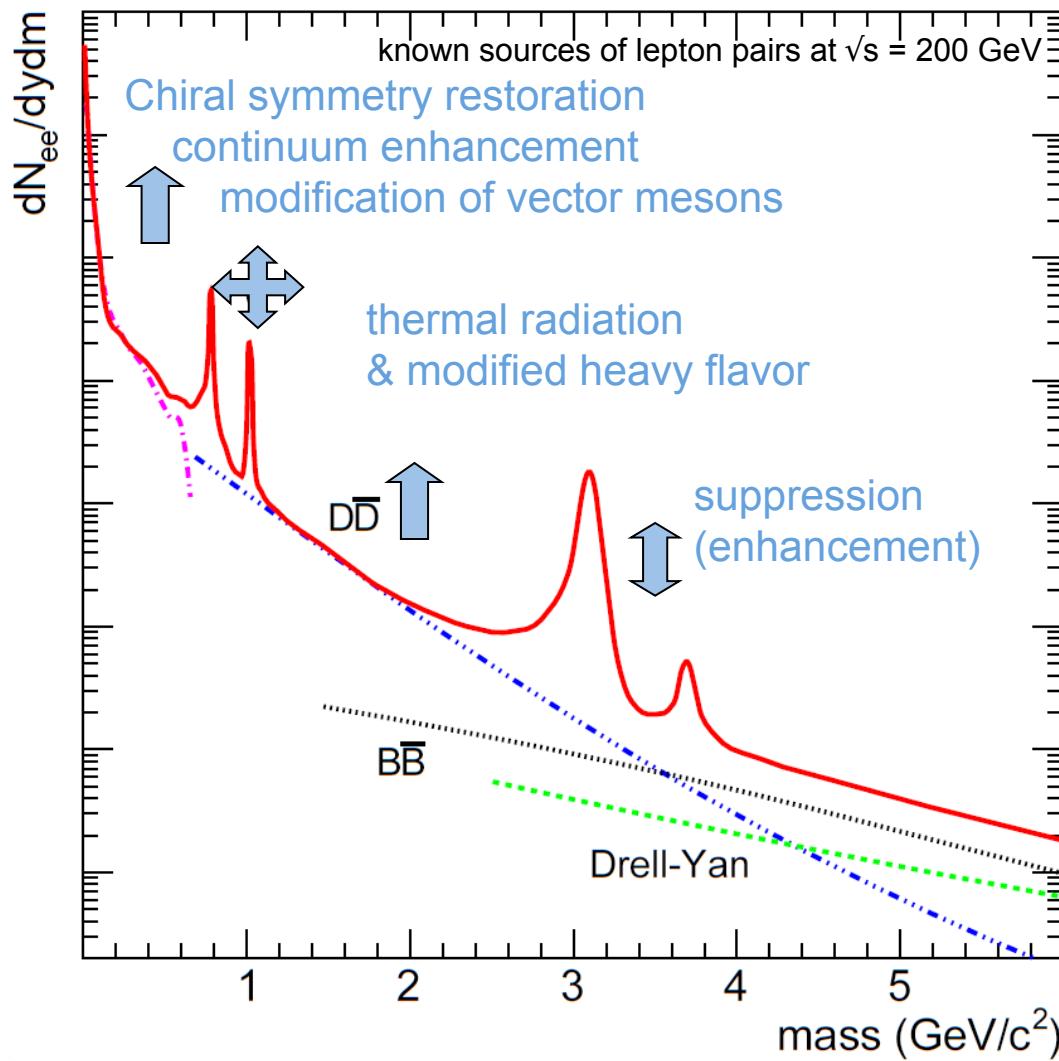


Jason Kamin, Stony Brook University  
PHENIX Collaboration  
RIKEN BNL Research Center Workshop  
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# Lepton Pair Continuum

*diverse physics*

## Modifications due to QCD phase transition



Large discovery potential at RHIC

# Estimate of Expected Sources

*creating the “cocktail”*

## Hadron Decays:

- Fit  $\pi^0$  and  $\pi^0$  data p+p or Au+Au

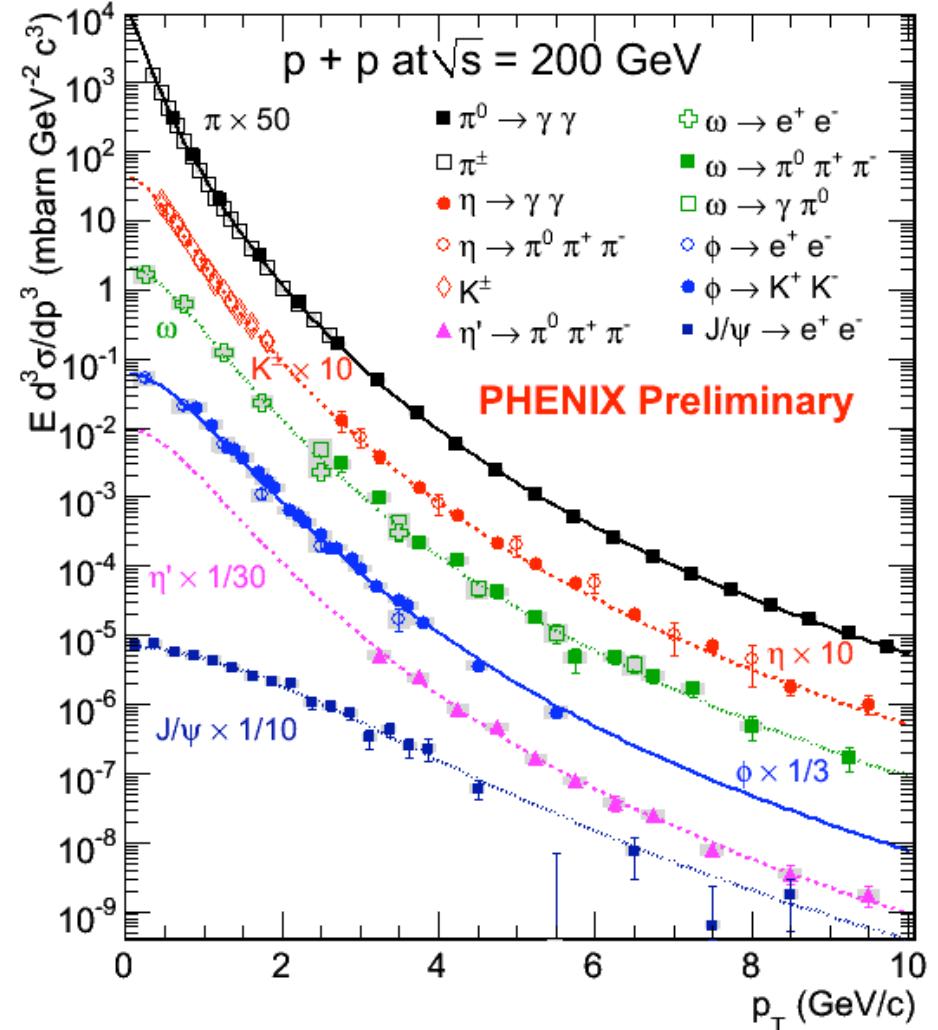
$$E \frac{d^3\sigma}{dp} = \frac{A}{(\exp(-ap_T - bp_T^2) + p_T/p_0)}$$

- For other mesons  $\eta$ ,  $\omega$ ,  $\rho$ ,  $\phi$ ,  $J/\psi$  etc. replace  $p_T \rightarrow m_T$  and fit normalization to existing data where available

Hadron data follows “ $m_T$  scaling”

## Heavy flavor production:

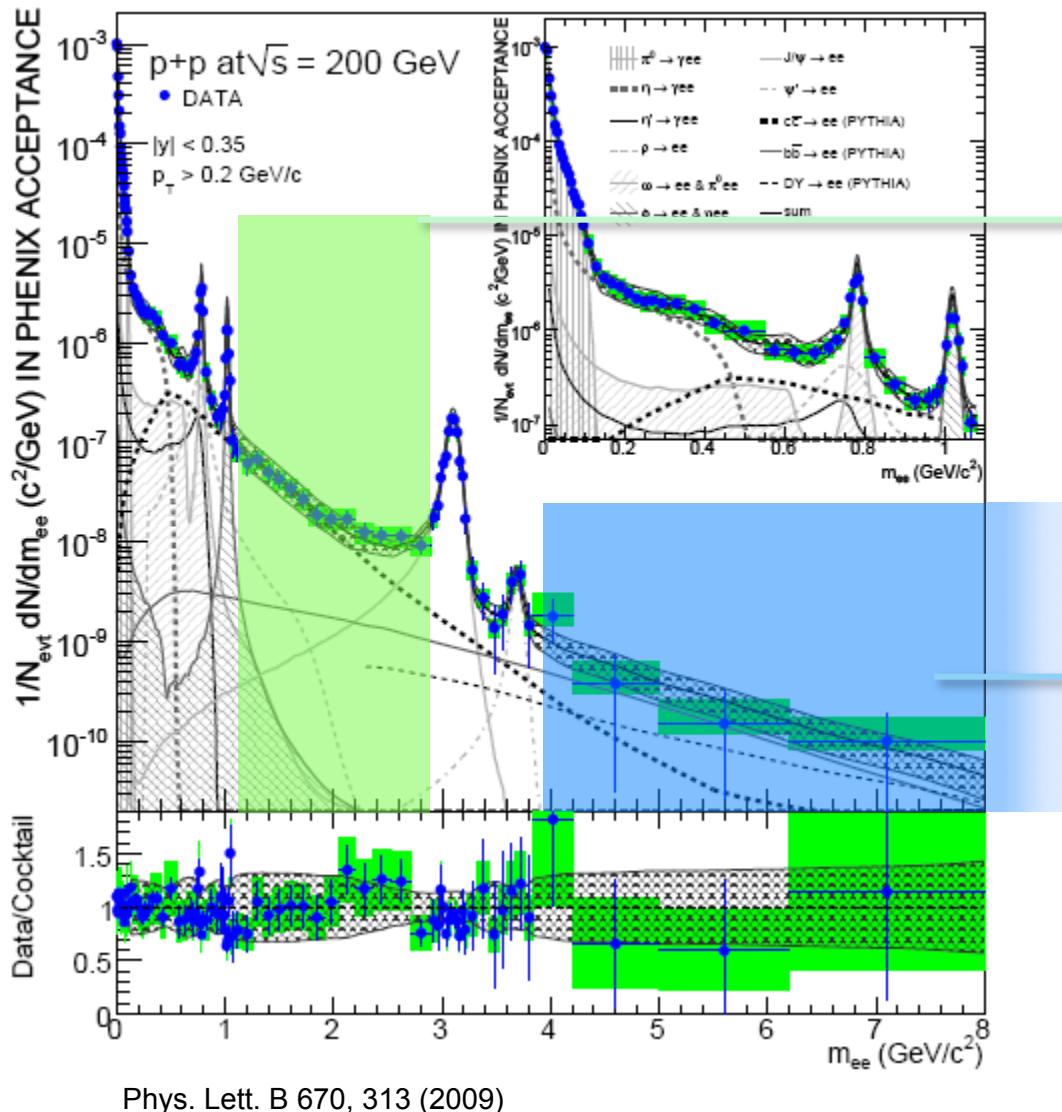
- $N_{coll} \times 567 \pm 57 \pm 193 \mu b$  from single electron measurement.



Predict contribution from known pair sources

# p+p Dielectrons

*agreement with cocktail*



## Low Mass Region:

- Excellent agreement with hadronic decay cocktail.

## Intermediate Mass Region:

- Open Charm Continuum
- integrating the yield:  
 $\sigma_{cc^-} = 544 \pm 39(\text{stat}) \pm 142(\text{syst}) \pm 200 \text{ (model)} \mu\text{b}$
- agrees with single electron x-sect:  
 $\sigma_{cc^-} = 567 \pm 57(\text{stat}) \pm 193 \text{ (syst)} \mu\text{b}$

## High Mass Region:

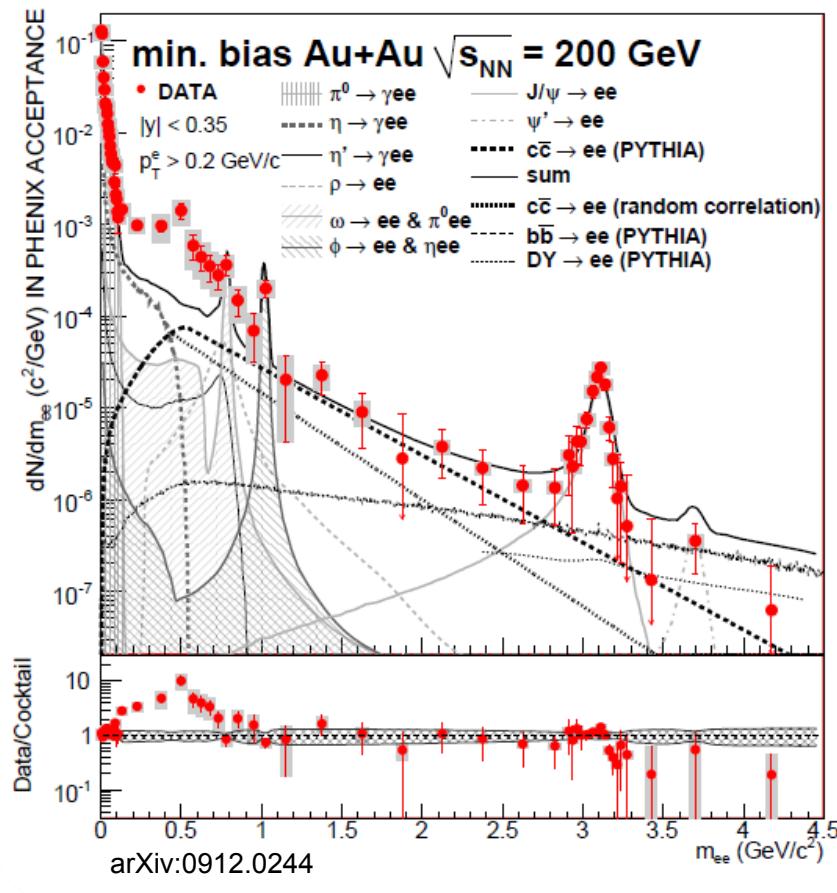
- Dominated by bottom  
 $\sigma_{bb^-} = 3.9 \pm 2.4(\text{stat})^{+3}_{-2}(\text{syst}) \mu\text{b}$

## Purpose of p+p:

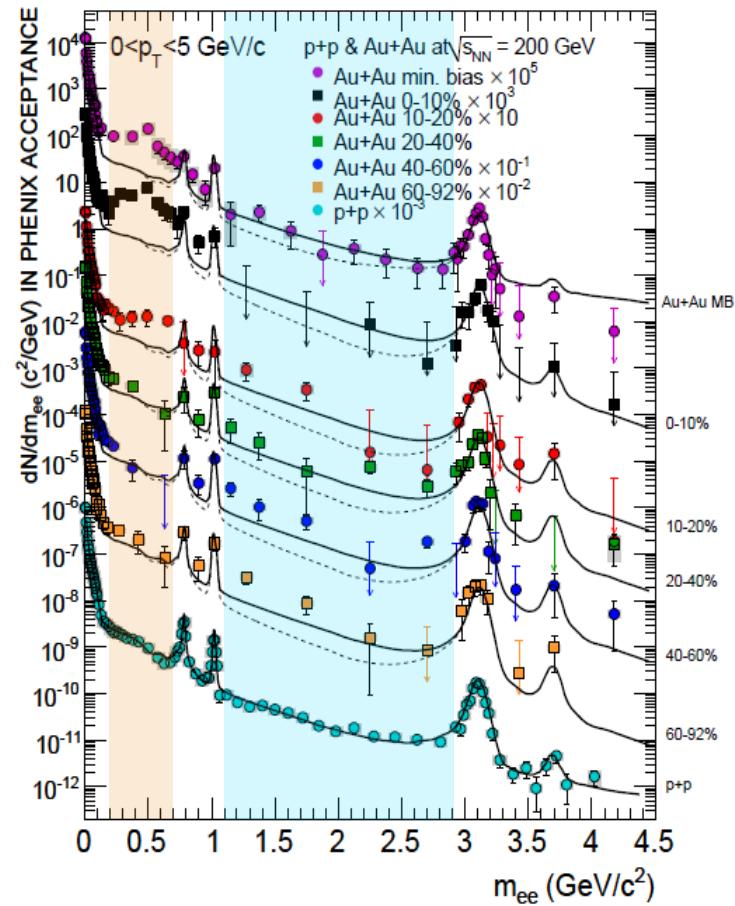
- Provides a baseline for Au+Au
- New channel to measure x-sect for charm and bottom

# Au+Au Dielectrons

*regions of enhancement*



- data and cocktail of known sources.
- striking enhancement below the  $\omega$  mass (LMR)
- Au+Au matches cocktail in IMR – surprise?

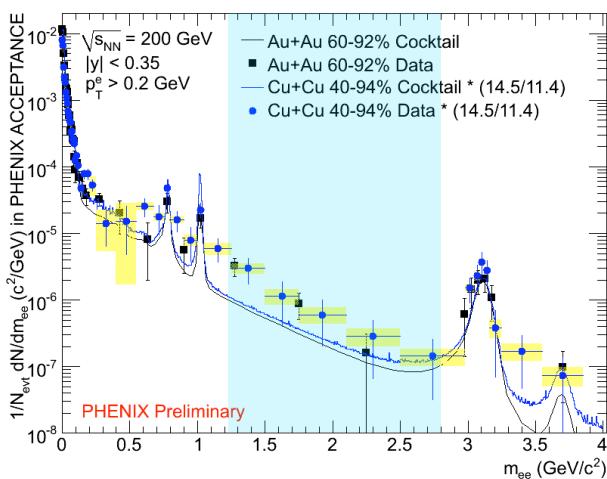
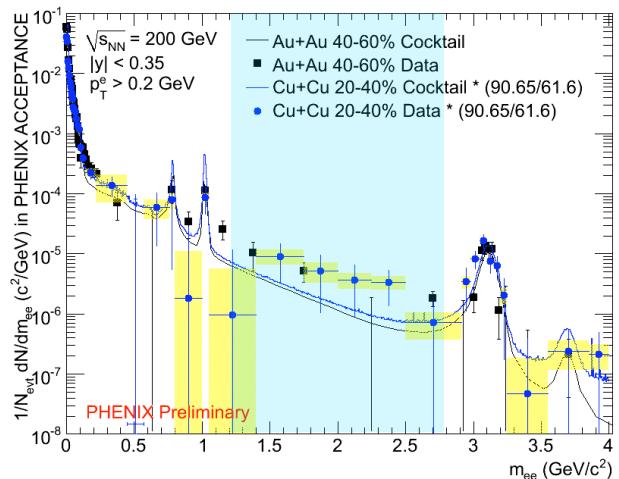
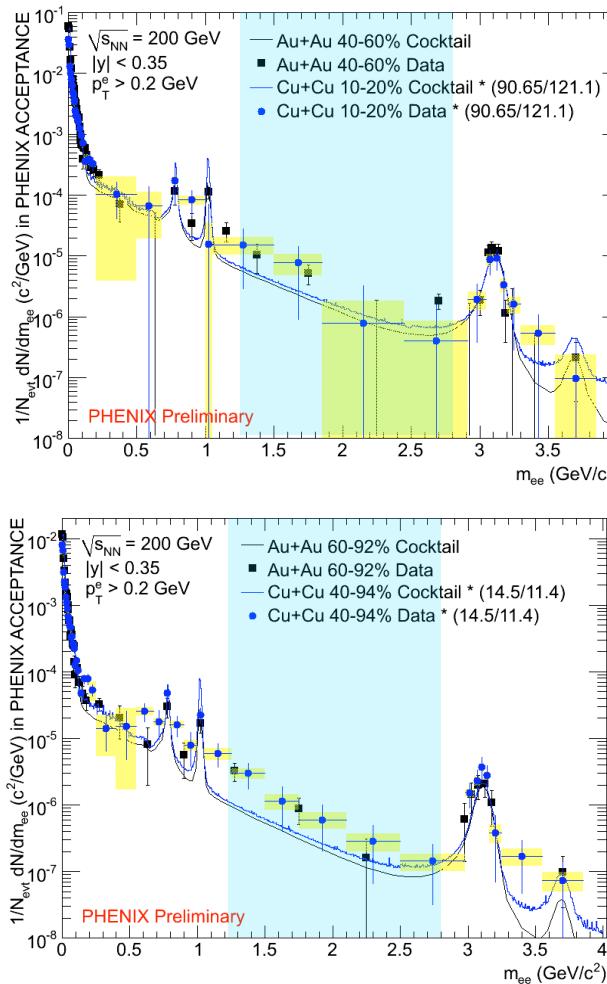
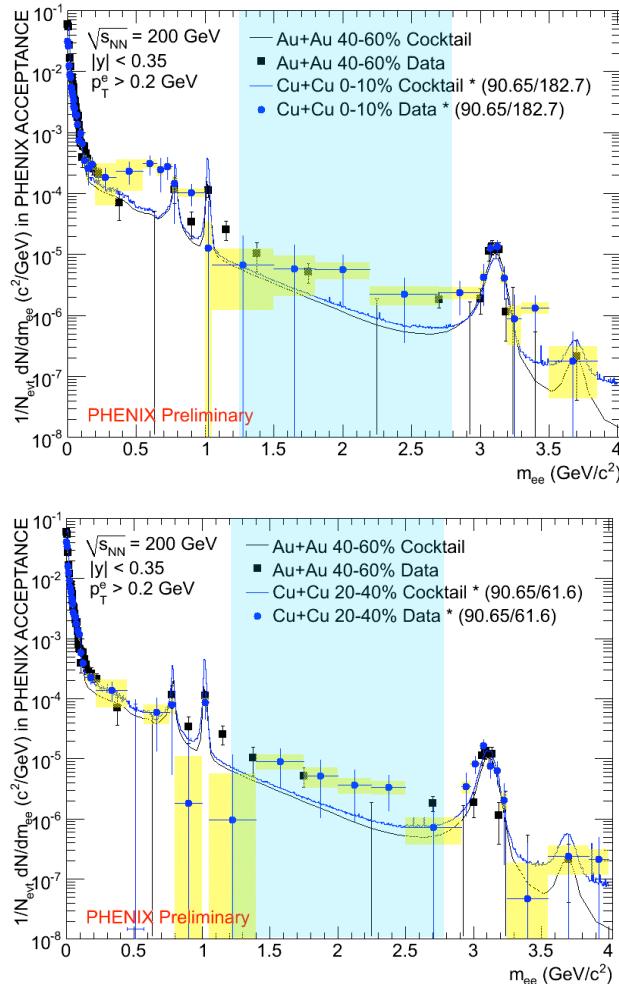


## Centrality Dependence

- LMR excess in more central
- slight IMR excess in more peripheral
- dashed line is result of max smearing of charm pairs

# Cu+Cu – Au+Au Comparison

*IMR enhancement*



Spectral modification should lower yield

- charm singles are known to be modified by the medium.
- these effects should lower the IMR yield in most central.

Prompt yields were observed by NA60 in this regime.

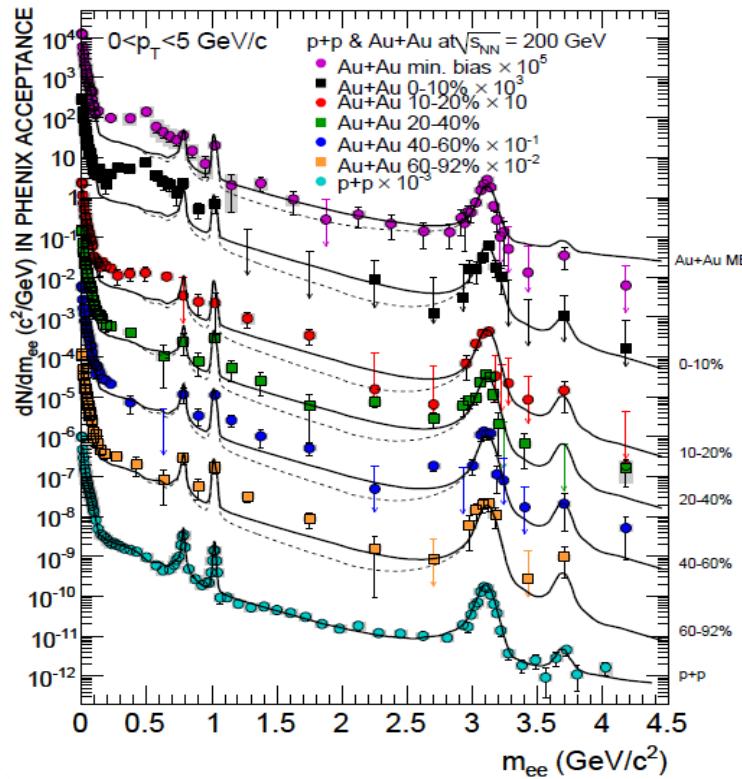
- prompt yields might rise with centrality

- Competing or compensating effects???

IMR excess also seen in peripheral Cu+Cu

# LMR Enhancement

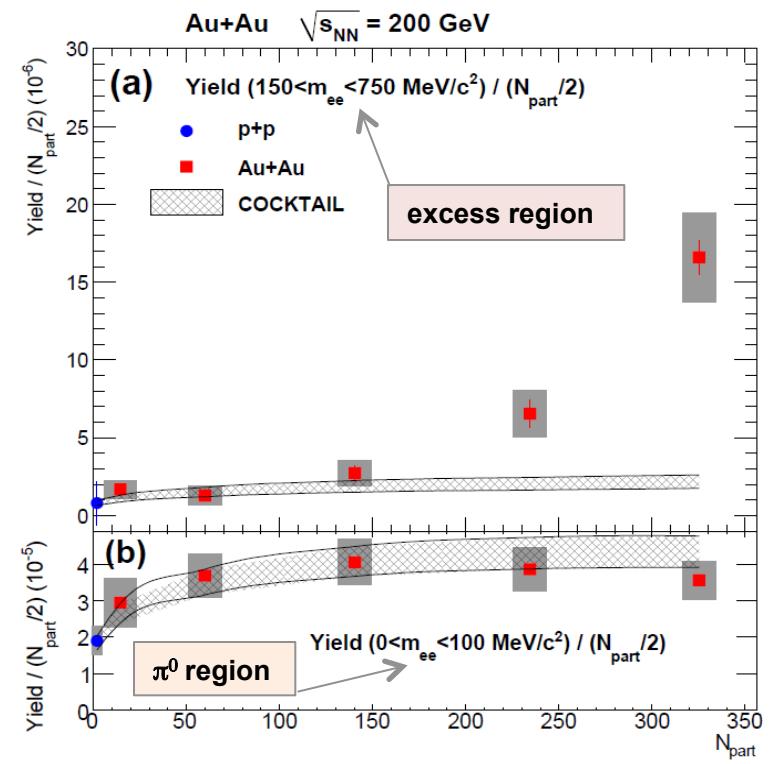
## Centrality Dependence



- Enhancement in low mass region is a strong function of centrality.
- Statistics are also sufficient to analyze  $p_T$  dependence.
- Need methodical approach to the spectra.

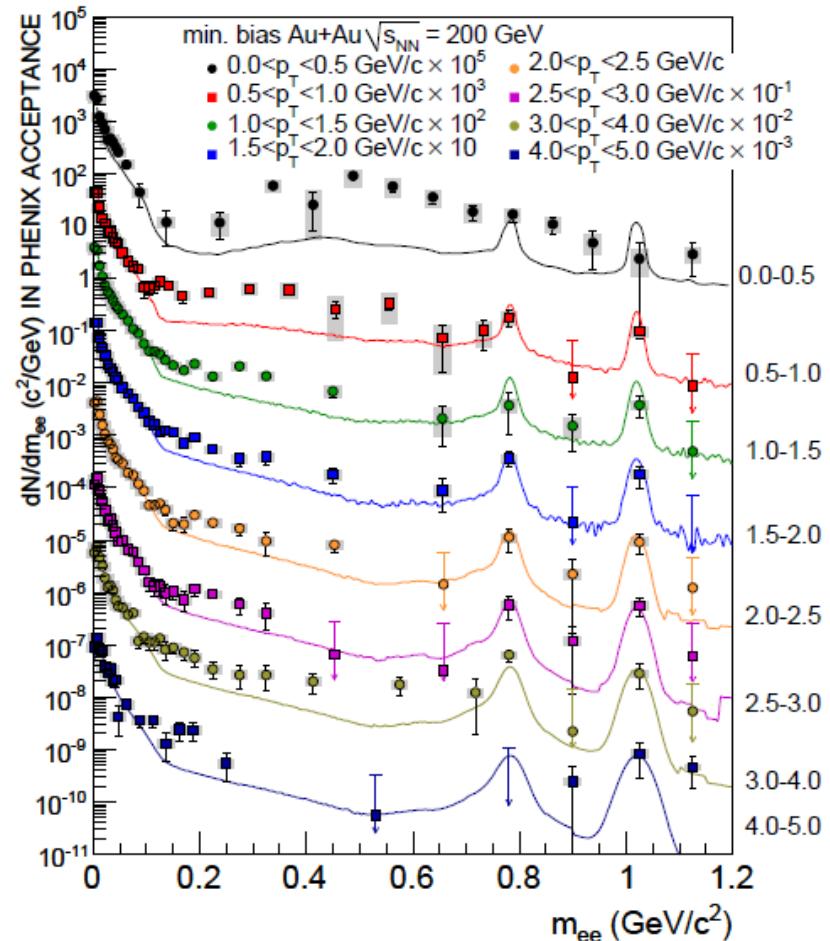
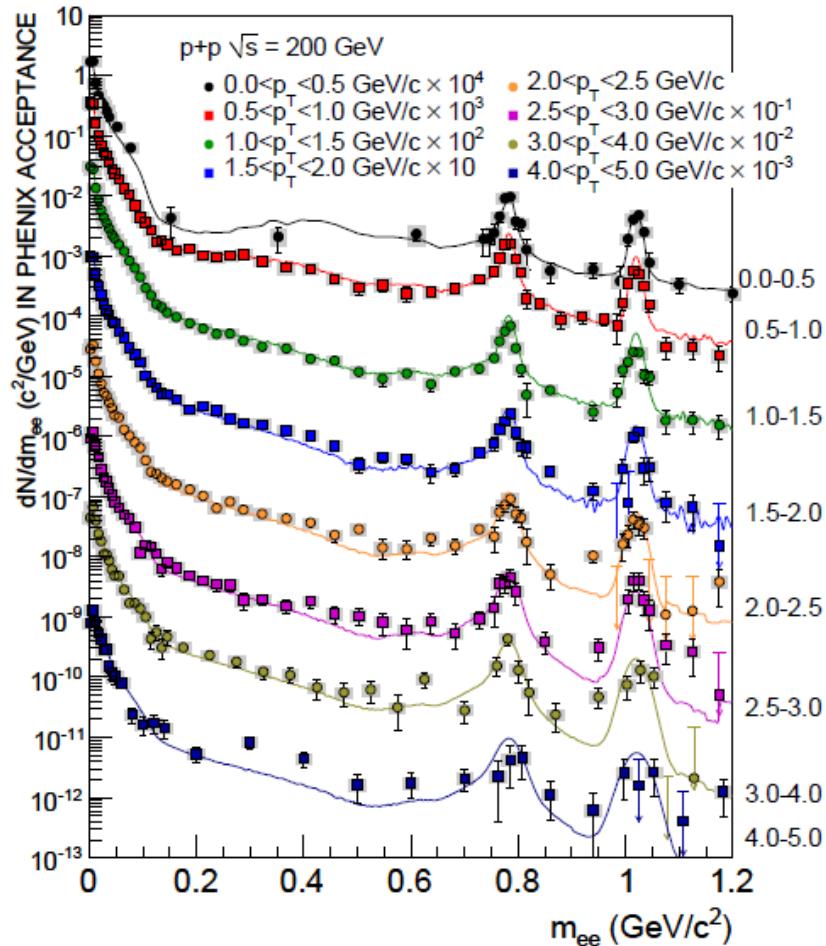
Excess mostly in central AuAu  
yield increase faster than  $N_{\text{part}}$

- $\text{Yield}/(N_{\text{part}}/2)$  in 2 mass windows (a & b)
- $\pi^0$  region scales apprx with  $N_{\text{part}}$
- Excess region:  
expect contribution from hot matter
  - in-medium production from  $\pi\pi$  or  $q\bar{q}$  annihilation
- yield should scale faster than  $N_{\text{part}}$  (and it does!)



# LMR Enhancement

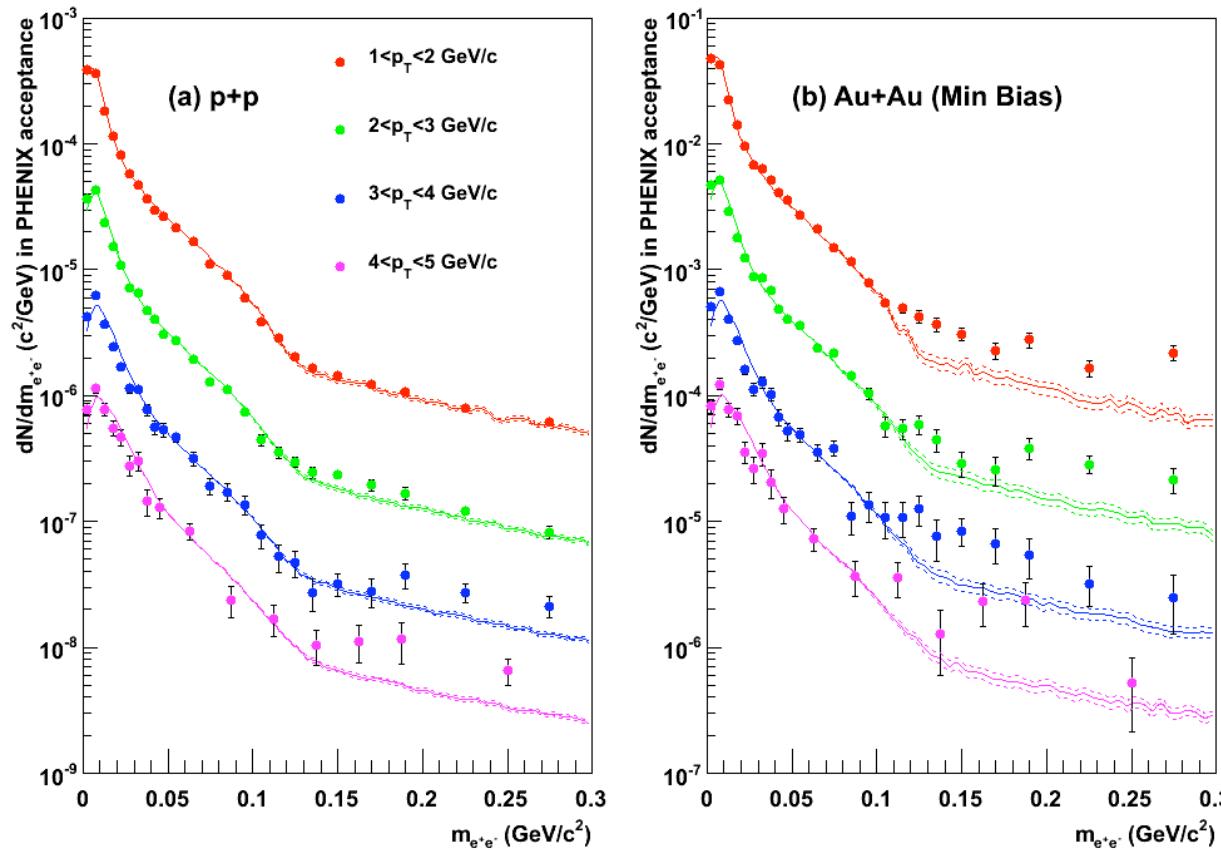
$p_T$  Dependence



- $p+p$  is described by hadronic cocktail.
- some excess at highest  $p_T$  from quark gluon compton scattering

- $\text{Au+Au}$  shows excess at all  $p_T$ .
- largest at lowest  $p_T$ .

# Direct Virtual Photons



## Measuring direct photons via virtual photons

- any process that radiates  $\gamma$  will also radiate  $\gamma^*$
- for  $m \ll p_T$ ,  $\gamma^*$  is “almost real”
- extrapolate  $\gamma^* \rightarrow e^+e^-$  yield to  $m=0$ 
  - ↳ direct  $\gamma$  yield.
- $m > m_\pi$  removes 90% of hadron decay background.

# Interpretation as Direct Photon

Relation between real and virtual photons:

$$\frac{d\sigma_{ee}}{dM^2 dp_T^2 dy} \approx \frac{\alpha}{3\pi} \frac{1}{M^2} L(M) \frac{d\sigma_\gamma}{dp_T^2 dy}$$

$$L(M) = \sqrt{1 - \frac{4m_l^2}{M^2}} (1 + \frac{2m_l^2}{M^2})$$

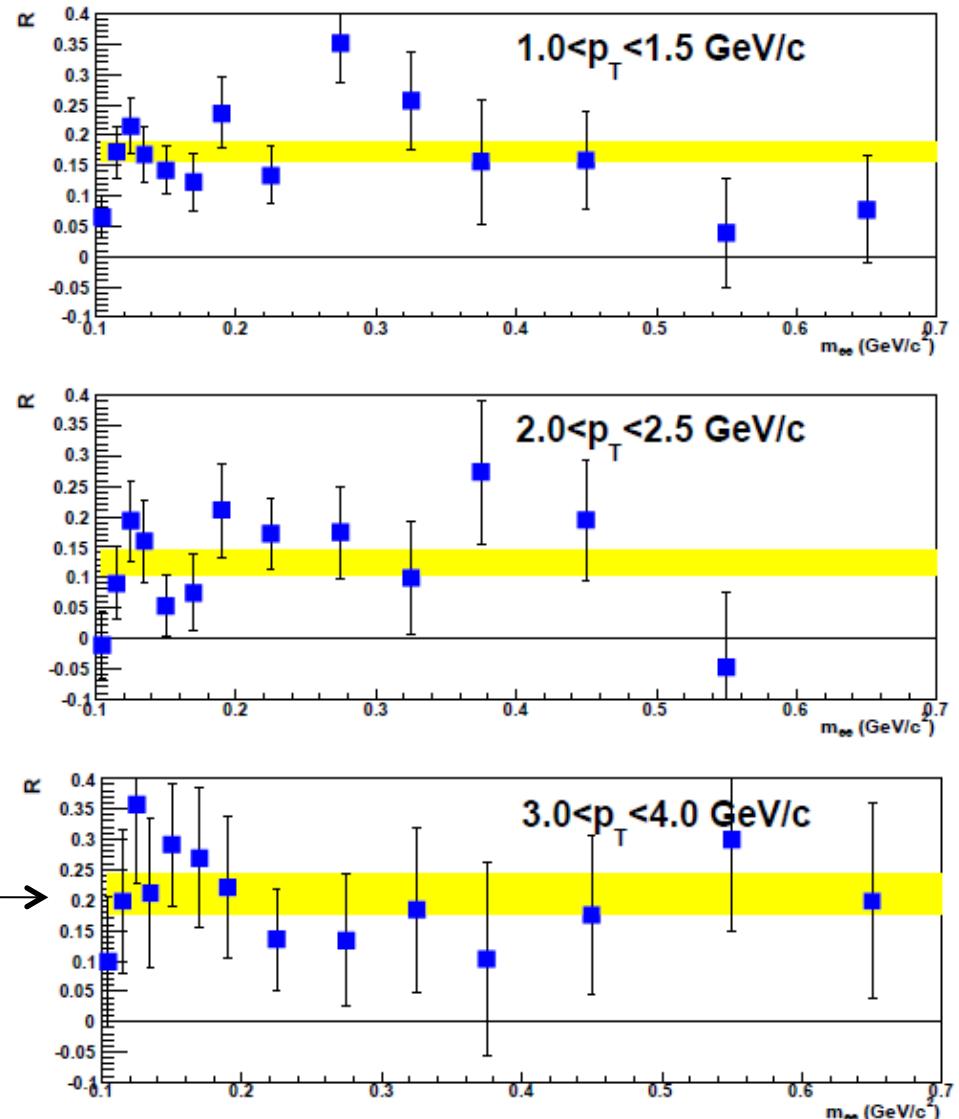
Extrapolate real  $\gamma$  yield from dileptons:

$$M \times \frac{dN_{ee}}{dM} \rightarrow \frac{dN_\gamma}{dM} \quad \text{for} \quad M \rightarrow 0$$

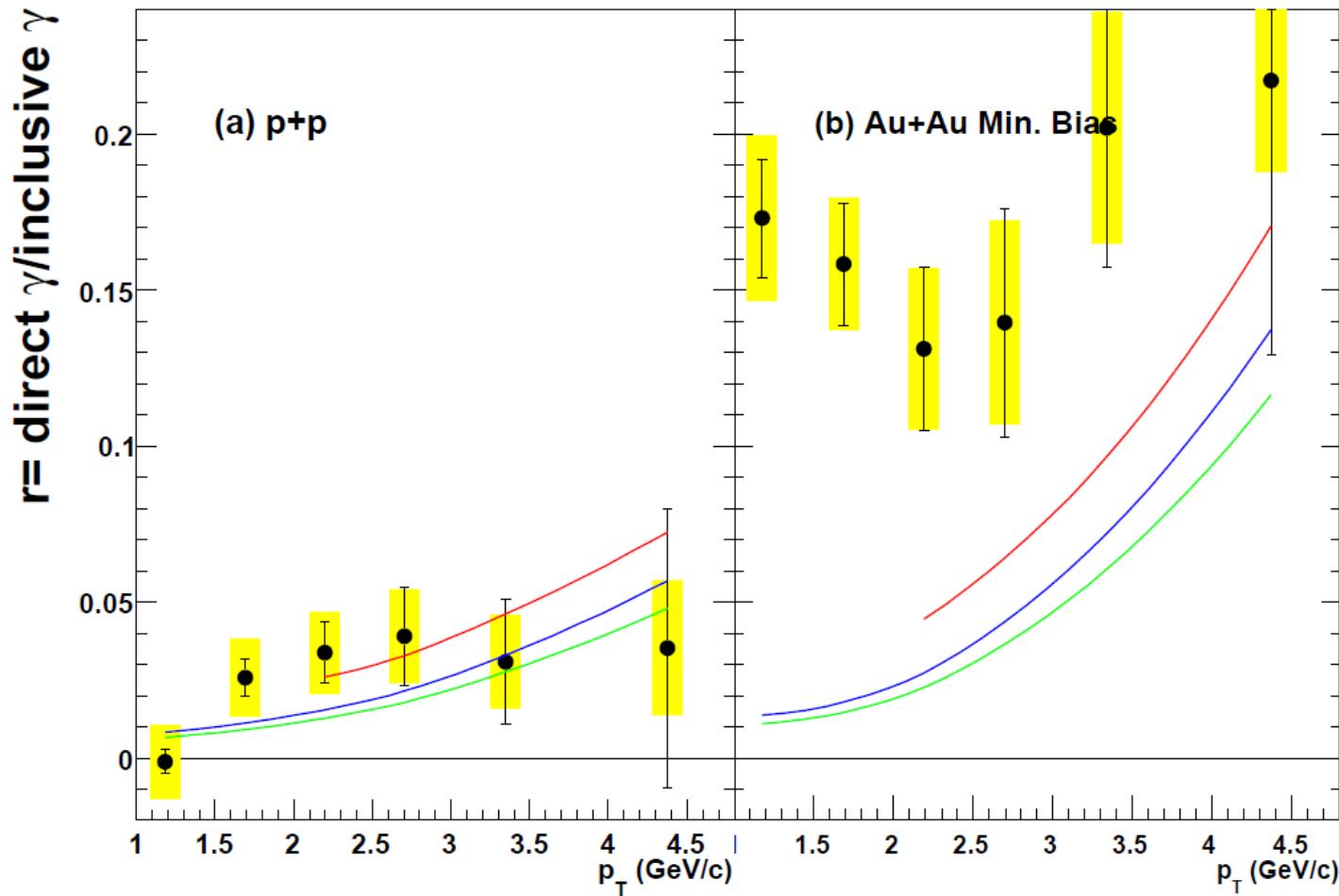
Virtual Photon excess  
at small mass and high  $p_T$   
can be interpreted as  
real photon excess

$$R = \frac{\text{direct } \gamma}{\text{inclusive } \gamma}$$

no change in shape.  
can be extrapolated  
to  $m=0$

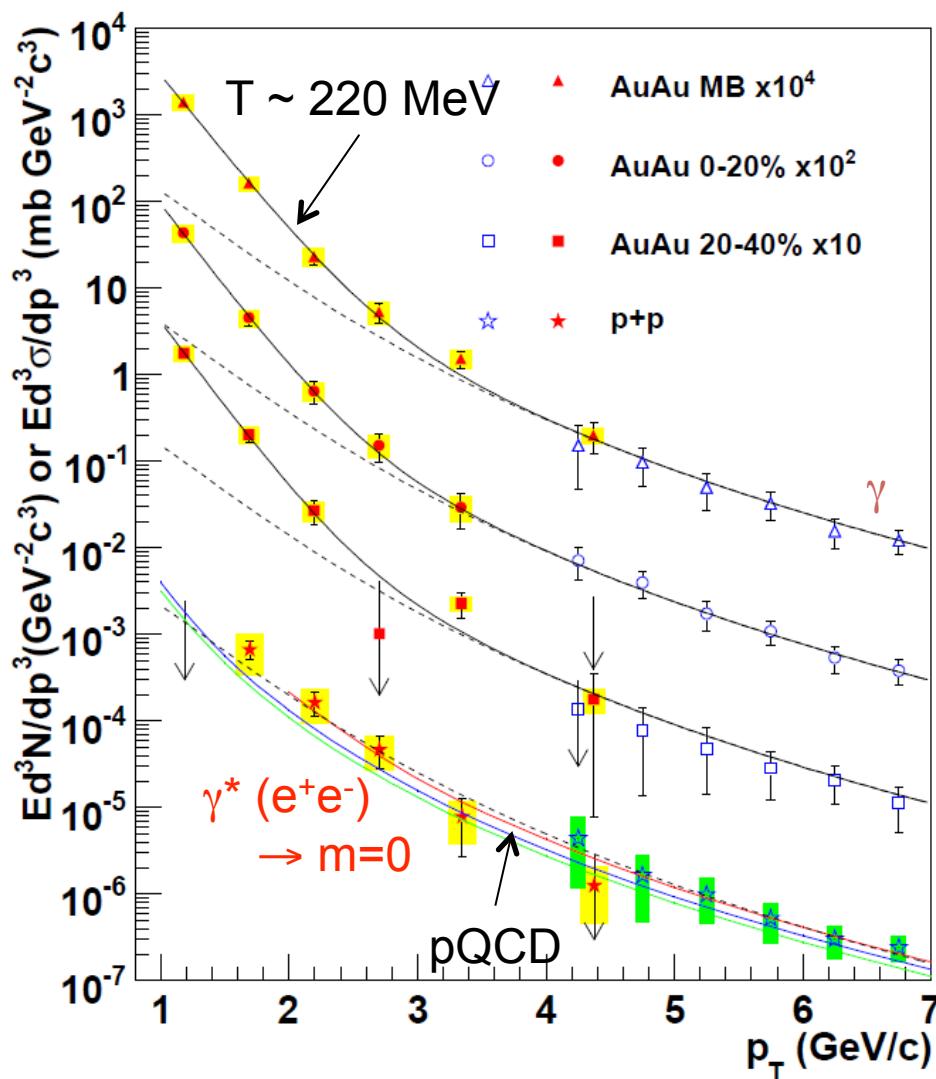


## Dilepton Excess at High pT – Low Mass



Significant direct photon excess beyond pQCD in Au+Au

# Thermal Radiation at RHIC



## Direct photons from real photons

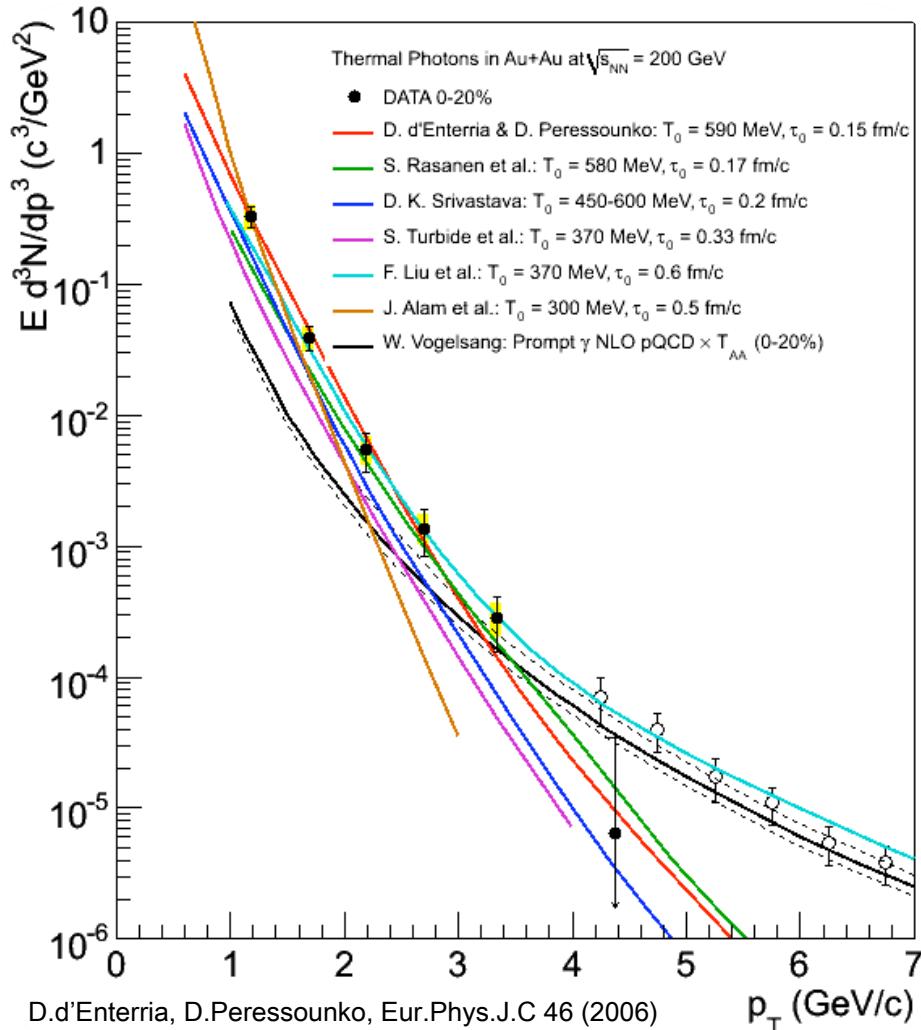
- measure inclusive photons
- subtract  $\pi^0$  and  $\eta$  decay photons at S/B < 1:10 for  $p_T < 3 \text{ GeV}$
- blue points

## Direct photons from virtual photons

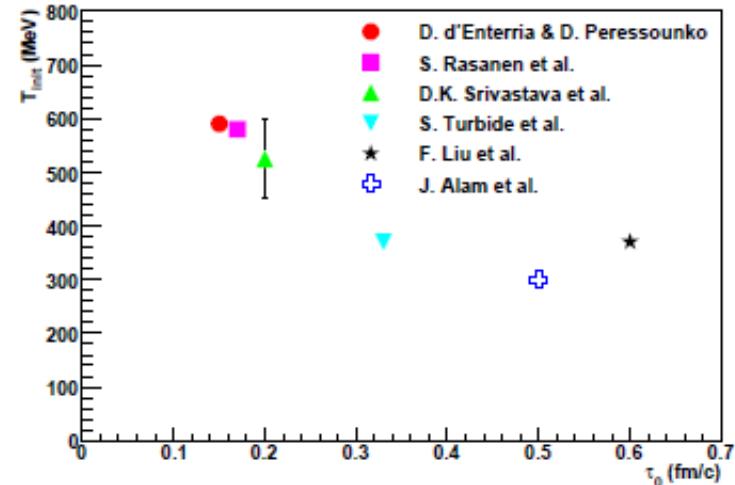
- measure  $e^+e^-$  pairs at  $m_\pi < m \ll p_T$
- subtract  $\eta$  decays at S/B  $\sim 1:1$
- extrapolate to mass = 0
- red points

First thermal photon measurement:  
 $T_{\text{ini}} > 220 \text{ MeV} > T_C$

# Calculation of Thermal Photons



$T_{\text{ini}} = 300 \text{ to } 600 \text{ MeV}$   
 $\tau_0 = 0.15 \text{ to } 0.5 \text{ fm/c}$



Initial temperatures and time from theoretical model fits to data

- 0.15 fm/c, 590 MeV (d'Enterria et al.)
- 0.2 fm/c, 450-660 MeV (Srivastava et al.)
- 0.5 fm/c, 300 MeV (Alam et al.)
- 0.17 fm/c, 580 MeV (Rasanen et al.)
- 0.33 fm/c, 370 MeV (Turbide et al.)

## Summary

Dileptons access interesting, diverse physics!

Well established p+p reference

- baseline for Au+Au, Cu+Cu, d+Au
- charm, bottom cross section measurements

Discovered low mass enhancement in central Au+Au

- strongly correlated to centrality
- mostly at low mass, low  $p_T$

First measurement of thermal photons

- extrapolation of quasi-real virtual photons to  $m=0$
- indicate initial temperature  $> 220$  MeV

Future work

- Ongoing Run10
  - HBD is installed to improve dielectron S/B
  - energy scan ( $\sqrt{s} = 200 / 62.5 / 39$  GeV)
- 2008 d+Au dielectron spectra coming soon...